RF TEST OF THE 1/3 SCALE MODEL CRAB CAVITY

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Introduction

A high luminosity, asymmetric electron-positron collider accelerator for B-factory (KEKB)[1] is being constructed at KEK. The colliding accelerator has a high-energy electron-synchrotron ring (HER, 8 GeV, 1.1 A) and a low-energy positron-synchrotron ring (LER, 3.5 GeV, 2.6 A). These rings have a finite angle colliding scheme at interaction region. To avoid beam instabilities and to collide head-on, beam bunches are deflected by time dependent deflecting voltage in RF cavities before and after the colliding region (crab crossing[2]). To realize the crab crossing scheme, a superconducting deflection cavity (crab cavity) was designed at KEK for KEKB[3] and at Cornell University for CESR-B[4]. The TM110 mode was selected for the crab cavity because of its high transverse shunt impedance. Since the TM110 mode has an unwanted polarization, the crab cavity was designed to have a squashed cell structure[5]. Another characteristic of the crab cavity is to provide a sufficient deflecting voltage for the finite angle beam crossing (11 x 2 mrad). Required voltages are 1.44 MV for HER and 1.41 MV for LER. To achieve this high voltage, the crab cavity should be operated stable at the surface peak field of 21 MV/m.

The R&D program has started since 1994 for the superconducting squashed cell crab cavity for KEKB[6]. In this program, we have fabricated three 1/3 scale model cavities. Objectives of the model cavities are; 1) establishing fabrication techniques for the squashed cell structure and 2) establishing treatments for the high surface peak field. After the fabrication and surface treatments, one of the model cavities was cooled down to 1.8 K and its RF performance was tested. After several surface treatments, the surface peak field reached to 43 MV/m, which is twice as much as the required value for the full scale crab cavity. The unloaded quality factor (Q_0) of the cavity was around 2×10^9. To investigate Q_0 degradation, the cavity was exposed to air. We observed significant Q_0

degradation. The cavity was contaminated by a small amount of hydrogen, oxygen, and nitrogen gases and tested their effects to the RF performance. We describe fabrication techniques and treatments of the 1/3 scale model cavity and present results of the RF performance test.

Fabrication and treatments

The 1/3 scale model cavity has the resonant frequency of 1.5 GHz in the TM110 mode. The cell has a squashed structure with a cross section of a race track shape. A ratio of long and short axes is about two. Dimension of the 1/3 scale model is shown in Fig. 1. Selected parameters of the cavity are listed in table 1. A half cell of the cavity was fabricated using a hydro-forming process. A niobium sheet 2.5 mm thick was supplied from TOKYO-DENKAI company. The RRR of the material was 171. The hydro-formed half cell was buff-polished and fringe of the call was trimmed. The edge of the cell was chemical-polished for welding. The half cells were welded by an electron-beam welding (EBM). After cavity cell was welded, two beam pipes and flanges were also electron-beam welded. The model cavity was barrel-polished mainly to remove seam of the EBM. Nb surface of about 50 μm was removed in the barrel polishing process. The cavity was then electro-polished using $HF+H_2SO_4$ (1:10 in vol.). Nb surface of about 100 μm was removed in this process. The cavity was rinsed for about 30 minutes with the high pressure water rinsing (HPR). We supplied ultra-pure water of 8 MPa at 10 l/min. The cavity was heat treated in an ultra high vacuum furnace at 700 ^{o}C for 5 hours. The cavity was enclosed by a Ti box at the heat treatment. The vacuum in the furnace was around 10^{-5} torr. The final treatment was the HPR to remove dusts on the cavity wall. This process was carried out in a clean room.

Table 1. Selected parameters of 1/3 scale model cavity

Frequency	1.5 GHz
Mode	TM110
Cell	Squashed cell
R/Q	48.9 Ω
Geometrical factor	227 Ω

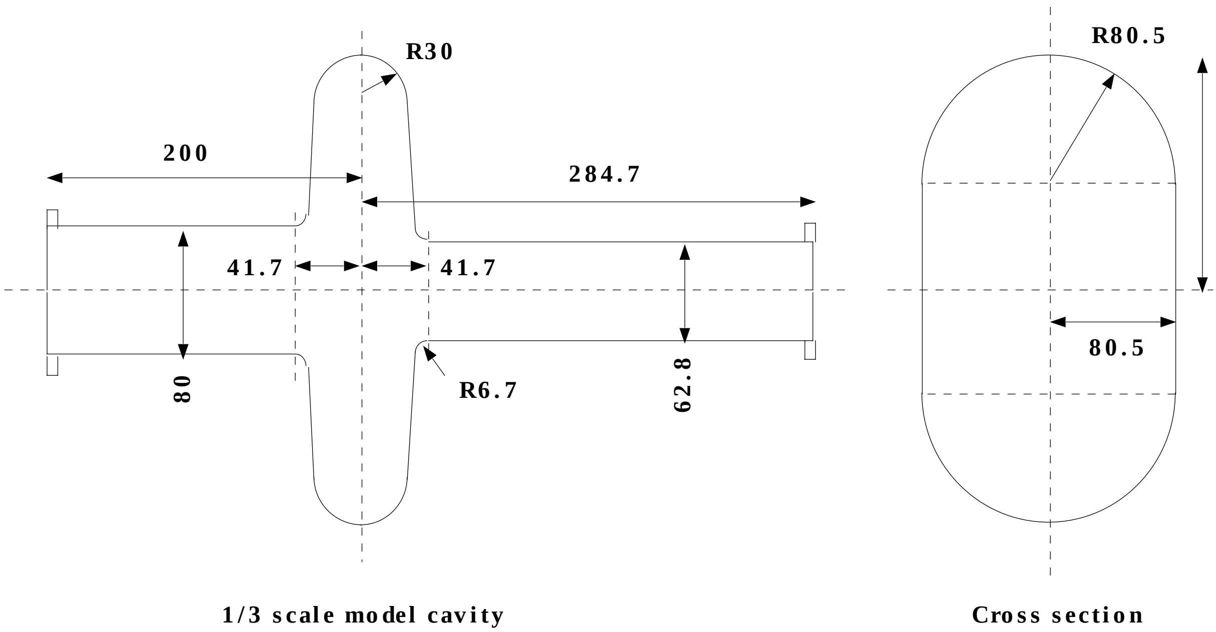

Figure 1. Dimension of 1/3 scale model cavity.

RF test of the 1/3 scale model cavity

RF performance test

After HPR, input and transmission probes were set to the cavity in a class 10 clean room. The cavity was evacuated by an oil-free pumping system. The cavity was baked at about 80 ^{o}C during pumping. After baking, the cavity was evacuated by an ion-pump to 10^{-9} torr and installed in a cryostat. A ferrite magnetic shield surrounded the cavity. A X-ray dose meter and a NaI scintillation spectrometer were set at the bottom of cryostat to detect X-rays produced in the cavity. The cavity was cooled down to 1.8 K in a saturated superfluid helium bath, then RF measurements were carried out. An 1.5 GHz RF system was built up for the RF measurement. The system has a 40 W power amplifier and a double-balanced mixer for phase detection. The loaded Q was determined from the decay time constant of the emitted power signal. The unloaded Q (Q_0) was determined from the power measurement of the continuous input, reflected and transmitted wave signals. The surface peak field in the cavity was determined from the calculation by MAFIA.

The best RF performance data is shown in Fig. 2. The Q_0 is plotted as a function of surface peak field. The surface peak field reached to 43 MV/m. The Q_0 is $2x10^9$ at low field levels and slightly decreases to $1.5x10^9$ at the maximum surface peak field. The temperature of the helium bath increased from 1.5 K to 1.8 K during the RF measurement. We observed X-ray radiation at 25 MV/m, 35 MV/m and above 40 MV/m, but the radiation was processed away in a short time. Above

43 MV/m, we could not continue further measurement because of unstable reflected signals and difficulty for phase lock.

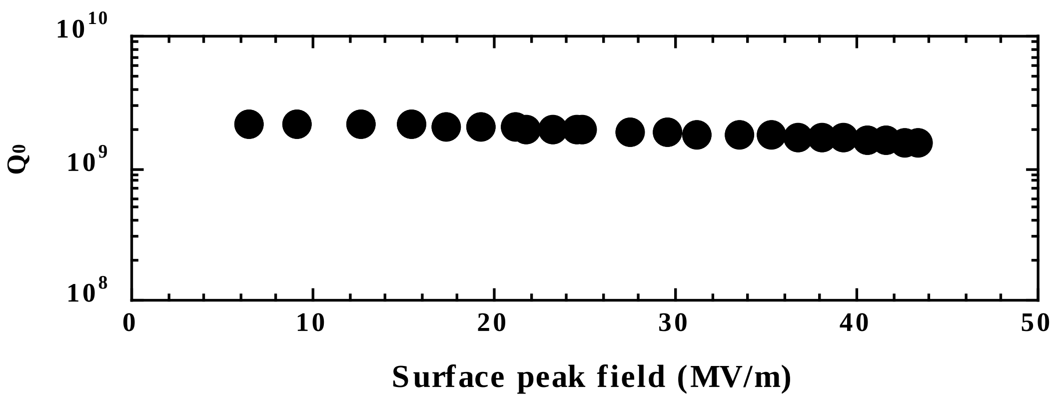

Figure 2. Q_0 vs surface peak field.

Air exposure test

To investigate Q_0 degradation by air exposure, we opened vacuum port of the cavity in a test room and exposed the cavity to air for 10 minutes. After we closed the vacuum port, we started evacuating and baking the cavity. We cooled the cavity and tested RF performance. The Q_0 is plotted in Fig 3 as a function of surface peak field together with the RF test data before the air exposure test. The Q_0 at low field was significantly low compared to the previous data. Above 12 MV/m, the Q_0 decreased rapidly as shown in Fig. 3. We observed strong X-ray radiation. After the air exposure test, the cavity was disassembled from the cryostat and rinsed by HPR. The cavity was assembled in the class 10 clean room again, and the RF performance was tested. The Q_0 recovered to $2x10^9$ and the surface peak field reached to 43 MV/m. HPR is effective way to cure Q_0 degradation of the cavity exposed to air.

The Q_0 before the air exposure test begins to degrade above 30 MV/m. The cavity had a leakage at a ceramic feedthrough of the input probe. The degradation of Q_0 may be caused by air contamination.

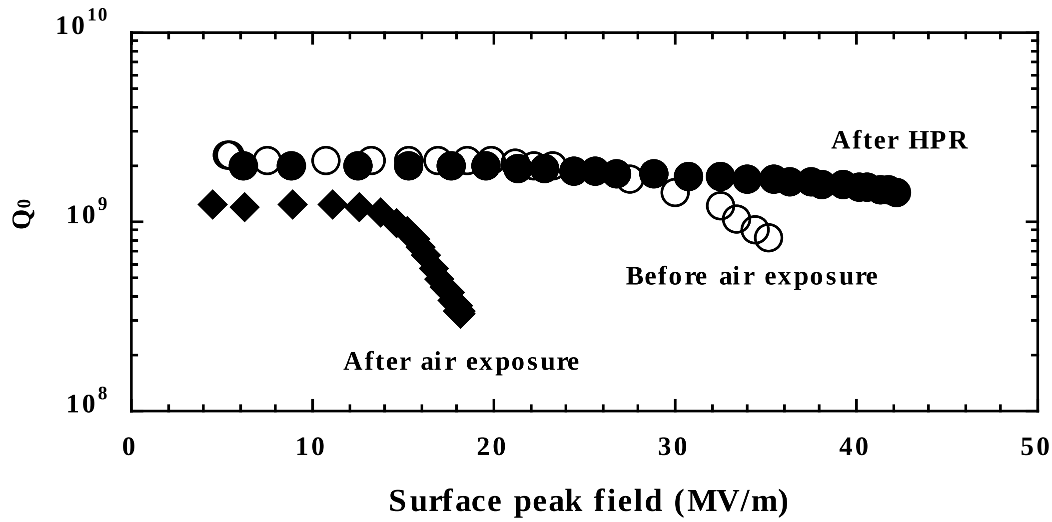

Figure 3. Air exposure test.

Gas contamination test

The cavity was contaminated by a small amount of hydrogen, oxygen and nitrogen gases to investigate Q_0 degradation by molecules trapped on the cavity wall. These gases were introduced into the cavity through a series of three filters (60, 15, and 0.5 μm). After the 1st RF test, we introduced hydrogen gas of 4 cc into cavity at 1.8 K. The 2nd RF test was carried out after 2 hours. The Q_0 did not degrade significantly. However, the surface peak field was limited at a lower level. The limitation was caused by unstable reflected signals and difficulty for phase lock. We increased temperature of the helium bath from 1.8 K to 4.2 K. A thermodynamic vapor pressure of hydrogen is less than 10^{-10} torr at 1.8 K, on the other hand, the pressure increases to the order of 10^{-6} torr at 4.2 K[7]. We introduced another hydrogen gas of 8 cc at 4.2 K and cooled the helium bath to 1.8 K again. We carried out the 3rd RF test. The surface peak field was limited at 20 MV/m. After these RF tests, we warmed up the cavity to 148 K, cooled down to 1.8 K, and carried out the 4th RF test. The 4th RF test showed about the same result as the 3rd RF test. We started pumping to remove hydrogen gas. Pumping the cavity, the 5th RF test was carried out. The field limitation recovered to 30 MV/m. We continued pumping, warmed up the cavity to 4.2 K, and cooled down the cavity to 1.8 K again. Pumping the cavity, the 6th RF test was carried out. The field limitation recovered to 43 MV/m. The hydrogen contamination test data are summarized in Fig. 4.

We warmed up the cavity to room temperature, evacuated hydrogen gas, and introduced nitrogen gas of 4 cc. We cooled the cavity and carried out RF test. The test results showed no significant Q_0 degradation and the surface peak field reached to 40 MV/m. We warmed up the cavity again and introduced nitrogen gas of 12 cc. The surface peak field reached to 43 MV/m. The nitrogen contamination test data are summarized in Fig. 5. We warmed up the cavity, evacuated nitrogen gas, introduced oxygen gas of 4 cc, and carried out the RF test. We did not observe significant Q_0

degradation and the surface peak field reached to 42 MV/m. The oxygen contamination test data are shown in Fig. 6.

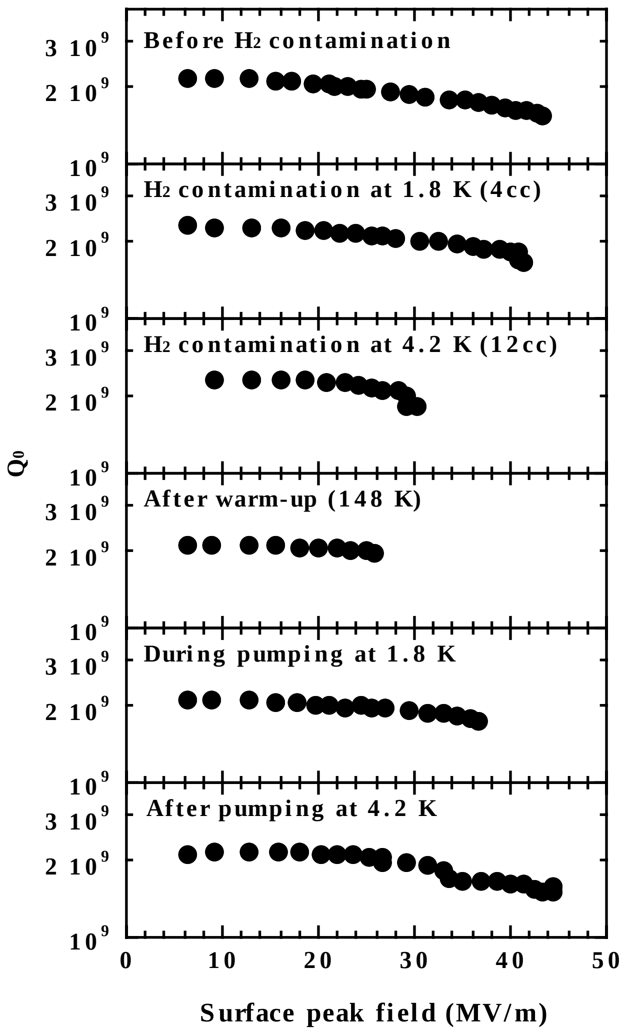

Figure 4. H_2 contamination test.

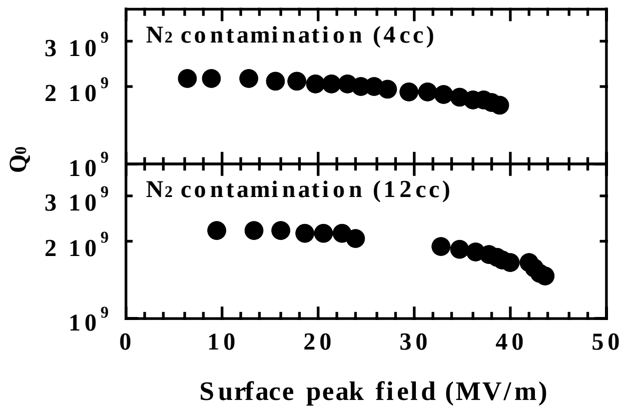

Figure 5. N_2 contamination test.

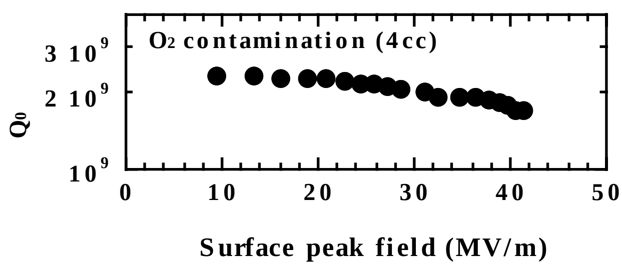

Figure 6. O_2 contamination test.

We did not observe significant Q_0 degradation of the cavity contaminated with hydrogen, nitrogen and oxygen gases. The surface peak field reached above 40 MV/m in the cavity contaminated by nitrogen and oxygen gases. The hydrogen gas-contamination test showed that the peak field is limited at lower levels.

Conclusions

To establish fabrication techniques for the squashed cell structure, and to establish treatments for high surface peak field of 21 MV/m, we have fabricated three 1/3 scale model cavities. The RF performance tests were carried out. The Q_0 of the cavity was $2x10^9$ and the surface peak field reached to 43 MV/m which is twice as much as the required value for the full scale crab cavity for KEKB. We confirmed that our fabrication techniques and treatments are applicable for the full scale crab cavities for KEKB. The full scale crab cavity was fabricated and tested recently. Results of the RF test are presented at this conference[8].

We examined the RF performance of the cavity exposed to air. We observed the significant Q_0 degradation. Strong X-ray radiation indicates that air dusts are the source of the Q_0 degradation. The RF performance of the air exposed cavity recovered after HPR. HPR is very effective way to cure the air-exposed cavity. We examined the RF performance of the cavity contaminated by a small amount of hydrogen, nitrogen and oxygen gases. The Q_0 of these cavities did not degrade significantly. However, the surface peak field is limited at lower levels in the cavity contaminated by hydrogen gas.

Acknowledgments

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